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Improved Regional Geological Understanding And Impact On The Hydrocarbon Prospectivity Of The West Mediterranean, Egypt

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Abstract

Egypt's west Mediterranean is a truly frontier basin in terms of hydrocarbon exploration, however, continued seismic data acquisition and exploration drilling scheduled for 2024/2025, is driving the region towards becoming an exploration hotspot. Regional 2D seismic data and a 24,000 sq km merged 3D seismic volume have recently been supplemented with two additional broadband 3D seismic volumes. Along with improved imaging, these recent seismic data allow interpreters to focus on stratigraphic elements and have more confidence in structural interpretation compared with 2D limitations.

The larger of the new multiclient 3D seismic surveys is located on the northwest of the offshore Nile Delta cone and west of the Rosetta fault trend, connecting the west to the more mature Nile Delta understanding and also having a direct tie to the Kiwi 1 well. The subsurface imaging is challenging, with complexities such as both dirty and clean evaporites as well as shale intrusions and extrusions being present. These challenges have been addressed using high-end depth imaging workflows. In the final 3D seismic volume, it is possible to extract spectacular channel systems in both Post and Pre-Messinian evaporite sections, using various seismic attributes, providing the interpreters with a better understanding of where high-quality reservoir facies may be located. Primary targets in this area are likely to be Oligo-Miocene clastic reservoirs in combination stratigraphic-structural traps, with secondary targets in the Pliocene shallow section.

In contrast, the second new multiclient 3D seismic survey is located far to the west and almost entirely on the shelf. These surveys are however linked by a large 3D merge volume, which allows the explorationists to have an excellent regional geological context. The new survey is extremely close to the Sidi Barrani 1 well, which was drilled on 2D data, and is thought to have failed due to poor trap definition. This is something the new 3D KPSDM depth seismic volume addresses, allowing explorers to better image and define traps in the area. Targets in this survey are most likely to be Jurassic and Cretaceous clastic reservoirs in structural traps.

Improved regional understanding has been achieved using these seismic data and this work highlights some of the imaging complexities and prospectivity using relevant seismic examples.

Introduction

Egypt's west Mediterranean Sea is frontier in terms of hydrocarbon exploration. Until approximately 2015, the region was covered by very little seismic data, and the only pre-salt well in the basin area was the Kiwi 1 well, drilled in 2010. The 1976 Sidi Barrani 1 well is located shallow waters, on the shelf, and targeted hydrocarbon plays comparable to the successful onshore Western Desert systems.

The offshore area can be broadly split into different geological domains based on regional 2D seismic data (Baer et al., 2017). The zones include shelf, transform margin, Mediterranean Ridge, Nile Delta extension and canyon systems. Prominent deep-seated features, such as the Rosetta trend/fault are clearly mappable on regional 2D lines spanning the Nile Delta and Herodotus Basin, giving the potential to link the west to the Nile Delta. Potential field data interpretation suggests that the Herodotus Basin is underlain by oceanic crust. Together with seismic imaging, it also indicates a sediment fill in excess of 15 km in some areas. Basin modelling based on regional 2D seismic suggests that potential Upper and Lower Cretaceous source rocks could reach sufficient maturity to expel hydrocarbons, but without more extensive well control, source rock presence and maturity will be difficult to de-risk further.

Anticipated hydrocarbon play types in the region have been explored by previous authors (e.g. Tari et al., 2012), though there are still many unknowns due to the early stage of exploration and lack of well penetrations.

A low risk approach to exploration is to try and extend plays from proven areas into neighboring areas. Following this strategy, there are two main hydrocarbon systems that are likely to be targeted in the region by upcoming exploration wells. The first is the potential offshore extension of the onshore Western Desert plays. This targets Cretaceous and Jurassic syn-rift and post-rift clastic reservoirs, similar to those targeted by the Sidi Barrani 1 well. This well targeted the Sidi Barrani Formation (Barremian age) and Khatatba Formation (middle Jurassic age) sandstones but was dry. The reason for failure is thought to be unreliable trap definition, a risk factor that will be reduced with new 3D seismic data now available in the area providing the means to accurately identify valid trapping geometries. There is good source rock potential in Barremo-Aptian shales with potential for oil, as well as oil and gas potential in Middle Jurassic (Khatatba Formation) dark shales.

The second hydrocarbon system that is most likely to be targeted is located off the shelf in the deeper basin. Primary targets in this area are likely to be Oligo-Miocene clastic reservoirs in combination stratigraphic-structural traps, with secondary targets in the Pliocene shallow section, plays that are proven in the adjacent Nile delta. Hydrocarbon discoveries have been made within the equivalent petroleum systems in shallow-water areas of the Nile Delta proper. The Pliocene deposits consist of slope and basin-floor turbidites in the form of channel/channel-levees and sheet sands. With some exceptions (e.g. Raven, Tamar and Leviathan), the Pre-Messinian fields are not DHI supported whereas the Post-Messinian fields are. The hydrocarbon fields in the deeper section are predominantly thermogenic whereas the fields in the shallower section are a mix of both biogenic and thermogenic. The only deep water well in the Herodotus Basin that tested pre-Messinian evaporite targets is the Kiwi 1 well, which encountered a poor primary reservoir in upper to middle Miocene sands, suggesting that an important part of achieving exploration success in this area is to be able to better map reservoir rock extent.

Data and challenges

Regional broadband multisensor 2D seismic data were acquired in two acquisition campaigns during 2016 and 2018, totaling 7 300 km and 22 400 km respectively. In addition, 10 300 km of legacy conventional 2D seismic were reprocessed using modern depth imaging workflows. These 2D seismic data formed the basis of a regional geological understanding and were used by companies to secure exploration concessions in Egypt's west Mediterranean Sea. Following the award of these concessions, five broadband multisensor 3D seismic acquisitions were conducted in a campaign spanning 2020 and 2021, to fulfill commitments and to drive the exploration programs forward on these concessions. The final KPSDM full stack volumes for each of these surveys were merged into a single 24 200 square kilometer full stack depth volume, spanning the shelf and transform margin as well as part of the basin and canyon systems.

Most recently in 2023 and 2024, two additional broadband multisensor 3D seismic acquisitions were completed over open acreage, adjacent to the existing seismic data (Fig. 1). Both surveys are over areas that have no existing 3D seismic data. The larger of the new 3D seismic surveys (Merneith, 6 180 square kilometers) is located on the northwest of the offshore Nile Delta cone and west of the Rosetta fault trend, connecting the west to the more mature Nile Delta understanding and having a direct tie to the Kiwi 1 well. The second new 3D seismic survey (Nefertiti, 2 710 square kilometers) is located far to the west, almost entirely on the shelf, and extremely close to the Sidi Barrani-1 well. These surveys are however linked by the large 3D depth merge volume mentioned previously, which allows the explorationists to have an excellent regional geological context between these two areas.

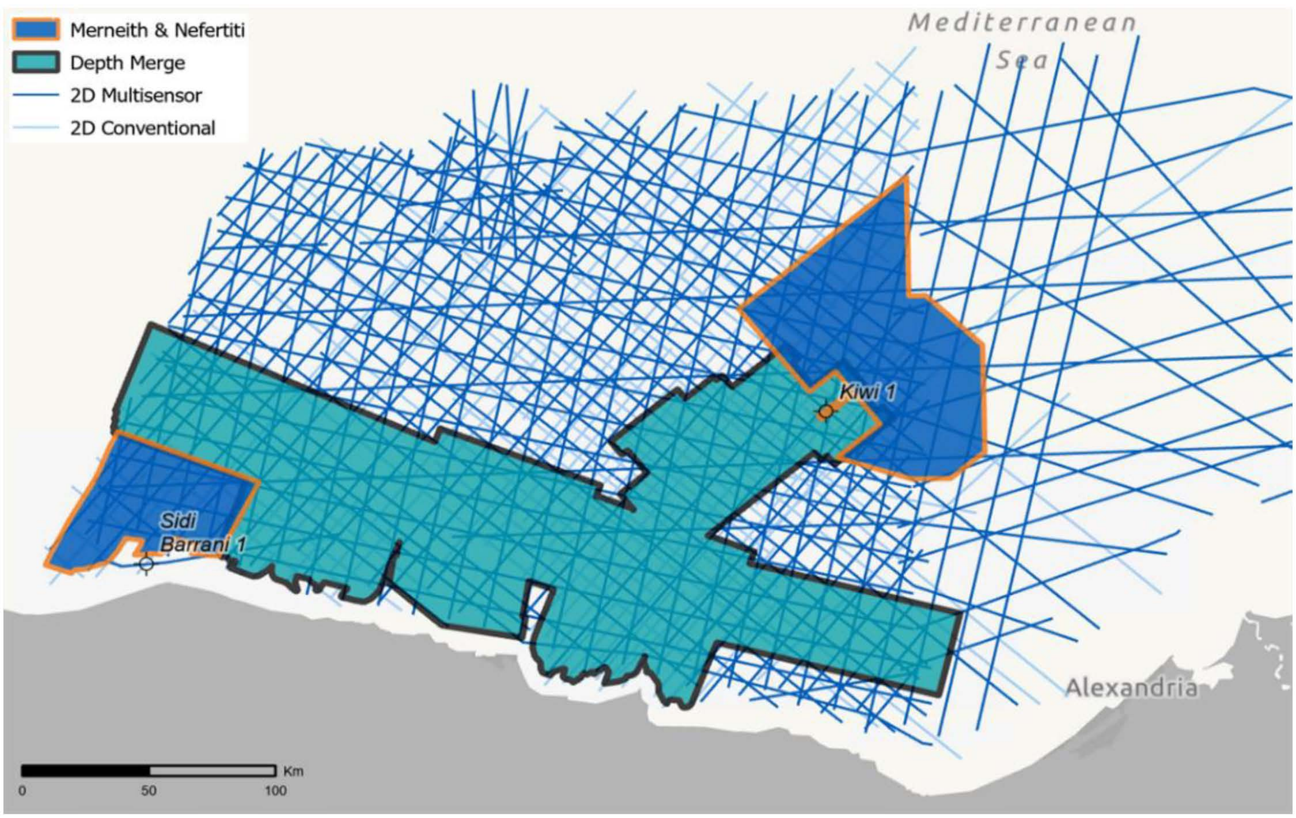

Figure 1—Map showing the location of the Nefertiti (western polygon with orange outline) and Merneith (eastern polygon with orange outline) 3D seismic surveys in relation to other seismic data discussed in this paper. Wells discussed in this paper are also indicated.

Final full integrity depth imaging for both these datasets is still ongoing, however, Fast Track KPSDM depth imaged volumes are available for both and have been used in this analysis. Depth imaging has been shown to be a critical process in accurately imaging with seismic in the eastern Mediterranean (e.g. El-Bassiony et al., 2018). However, there are a number of challenges that need to be addressed in order to obtain an accurate velocity model. One important factor is obtaining a reasonable velocity for the Messinian evaporites. These are not simply clean high velocity halite as observed in other salt provinces but contain a significant amount of complexity and heterogeneity, as discussed in detail by other authors (e.g. Roveri et al. 2014; Feng et al. 2016). Figure 2 illustrates the variability of the Messinian evaporites within the Merneith survey alone. The high amplitude events within the Messinian evaporite section are likely clastic layers. The level of deformation of these layers gives an indication of the deformation that this layer has undergone.

As observed in Figure 2, the thickness of the layer, the amount of clastic inclusions, the deformation of the layer and the vertical level at which the clastic inclusions are located differ throughout the survey. It is therefore essential that there is a variable velocity used within the Messinian evaporite layer to flatten the seismic gathers and have a reliable velocity model for the imaging, resulting in a more accurate pre-salt image. Velocity analysis of the Messinian salt reveals an interval velocity range from 3900 to 4800 m/s averaging around 4350 m/s.

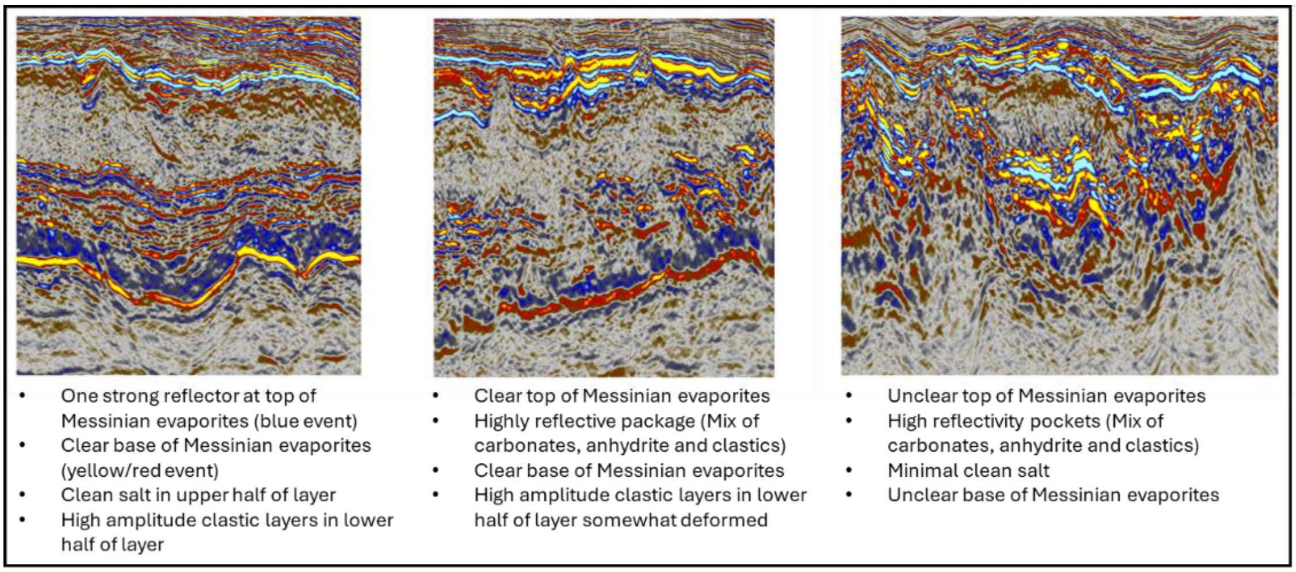

Figure 2—Panel showing the variable Messinian evaporite layer within the Merneith survey area – Full stack KPSDM fast track volume. The simplest example (left) showing a clear top (blue event) and base (yellow/red event) of layer, with a cleaner/halite-rich upper portion and a lower portion that contains high amplitude clastic events. In the middle example, the top and base are still well resolved, however there is a highly reflective package at the top boundary, likely comprised of carbonates, anhydrites and clastics. Additionally, the clastic events in the lower portion of the layer are more deformed. The most complex example is to the right, where there is minimal clean/halite-rich salt, the top and base are not easily resolved and there are high amplitude events above and within the Messinian evaporite layer.

Mobile shales have been recognized as a challenge for seismic imaging in many parts of the globe (e.g. Soto et al. 2021, Van Simaeys et al. 2021). These have been identified in many parts of the eastern Mediterranean, including the Egypt's west Mediterranean Sea. They have an unclear seismic expression as they generally have a low acoustic impedance contrast with many other sedimentary rocks. Typically, they appear as transparent bodies on the seismic. They can have complex geometries and spatial variations and their seismic response and velocities can depend to a large degree on the overpressure and fluid content, which are difficult to predict and may change quickly within a survey area. Fig. 3 shows two complex shale bodies that are present in the Merneith survey. These shales can be both intruded into the Messinian evaporites, extruded above them, and in some cases in the Mediterranean, extruding to seabed to form present day mud volcanoes. The larger shale bodies are mapped and included in the velocity model building process during imaging and a range of velocities are tested to obtain an optimal representation in the velocity model.

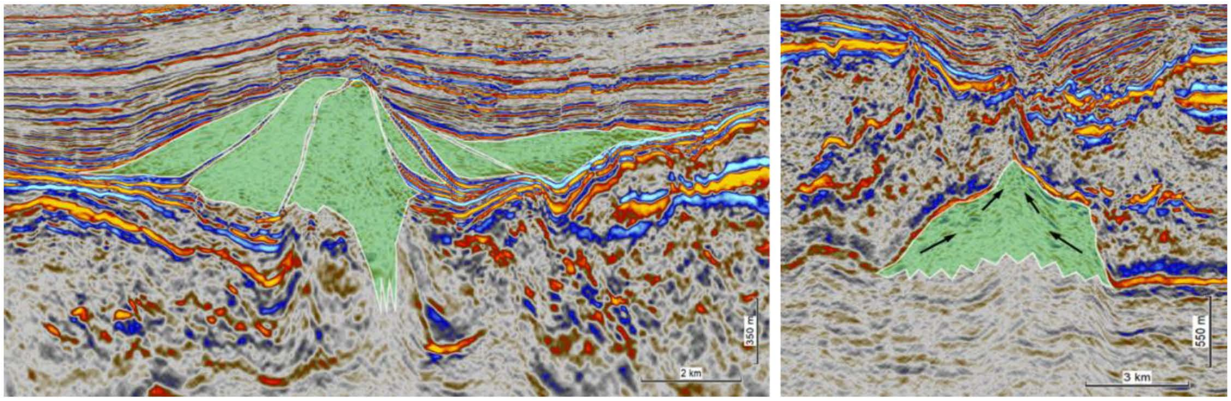

Figure 3—Examples of mobile shale bodies (transparent green) which complicate the seismic imaging in the area. In the left example, there is clear evidence of multiple episodes of mobile shale extrusion on top of the Messinian evaporites. In the example on the right, there is a mobile shale structure (transparent green) at the base of the Messinian evaporites (yellow/red event) that has begun to intrude into the evaporites, but not quite managed to penetrate the evaporite later.

Observations and results

A broad understanding of the basin architecture had been gained from the previous regional 2D seismic data (Baer et al., 2017), and so it was expected that these two new 3D seismic surveys in Egypt's west Mediterranean Sea would cover areas that are vastly different in terms of imaging challenges and potential exploration targets. In addition to the regional 2D seismic, they can be put into context using the 3D Depth merge volume that links the two (Fig. 1) from the outer Nile (Merneith), through the Herodotus Basin, transform margin, and onto the shelf area (Nefertiti). The 3D allows for improved imaging capabilities and the possibility to look at stratigraphic features and 3D structures that are difficult to do confidently using a grid of 2D data. It also allows for a direct tie to the Kiwi 1 well.

Within the post-Messinian section of the Merneith survey, there are many high amplitude soft events near to faults and crests of small structures. This is consistent with what can be observed in the inner Nile Delta and likely indicates the presence of a working hydrocarbon system. It is possible to extract stunning leveed channels and channel complexes using seismic attributes such as RMS amplitudes and spectral decomposition (e.g. Fig 4) in both the pre- and post-Messinian sections. This is only possible using 3D seismic and highlights the importance of this dataset in defining potential targets with good reservoir properties – something that was a reason for failure for the nearby Kiwi 1 well. These results will be even more definitive using the seismic volume from full integrity processing that is ongoing, which incorporates the sonic velocity information from the Kiwi 1 well. The results in Fig.4 demonstrate that this area is part of a gateway feeding sediment from the Nile Delta proper into the more distal/basinal areas. These channels and channel complexes can be up to five kilometers wide and extend in a northwesterly direction.

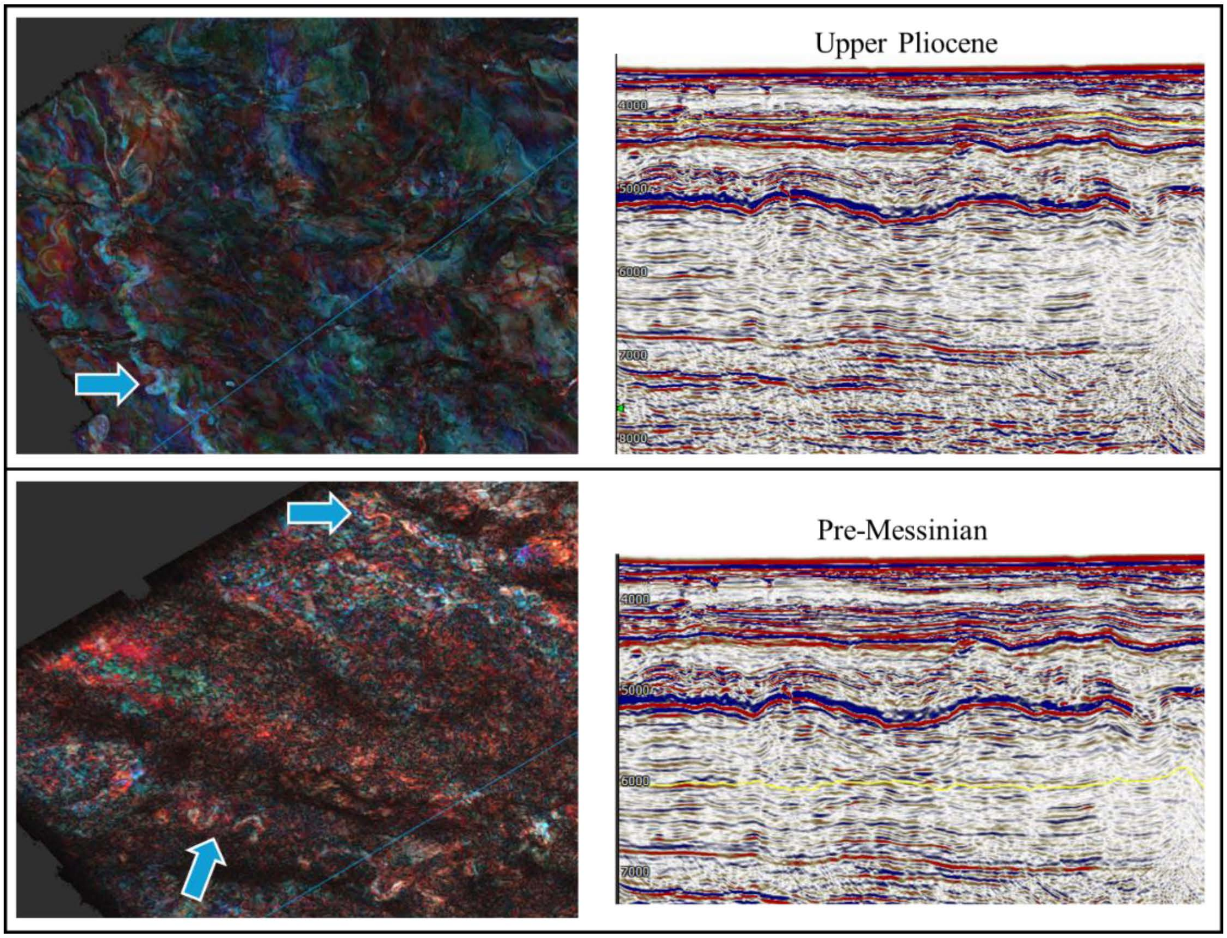

Figure 4—Spectral decomposition at two horizon levels extracted from the Full stack KPSDM fast track volume. Top panel shows the RGB blend (Red = low frequency, Green = mid frequency, Blue = high frequency) for a horizon in the upper Pliocene section. The level of the horizon is shown by the yellow line on the seismic section to the right, and the location of the seismic section is indicated in the map view by the blue line. The same display convention is used in the lower panel for a horizon in the Pre-Messinian section. Clear channel systems (blue arrows) can be observed in both the Upper Pliocene and Pre-Messinian spectral decomposition maps, despite this being extracted from a sub-optimal fast track volume.

The Nefertiti survey, to the extreme west of the Egypt west Mediterranean Sea, is located largely on a shelfal area. The advantage of this area in terms of imaging is that there is minimal Messinian evaporites and mobile shales to complicate the seismic imaging, however, as has been observed in other seismic datasets along the shelf (within the Depth Merge, Fig. 1), this does not mean that the velocity models are simple. Although far from infrastructure, this area is close to shore and in relatively shallow water depths, potentially making drilling and exploitation cheaper. The target reservoirs in this area are most likely to be Sidi Barrani Formation (Barremian age) and Khatatba Formation (middle Jurassic age) sandstones, as was the case in the adjacent Sidi Barrani well which was plugged and abandoned with oil staining (Fig. 1). This well reportedly failed due to the lack of a valid trap. The drilled structure was mapped on 2D data and this new 3D dataset will assist in defining traps more confidently. There are some strongly faulted areas along the transform margin (Fig. 5), making tilted fault blocks a potential trapping mechanism in the deeper water areas. Moving up onto the shelf itself, there are some slightly more subtle structural targets that are likely to be structures of interest for exploration (Fig. 5) once fully mapped in 3D.

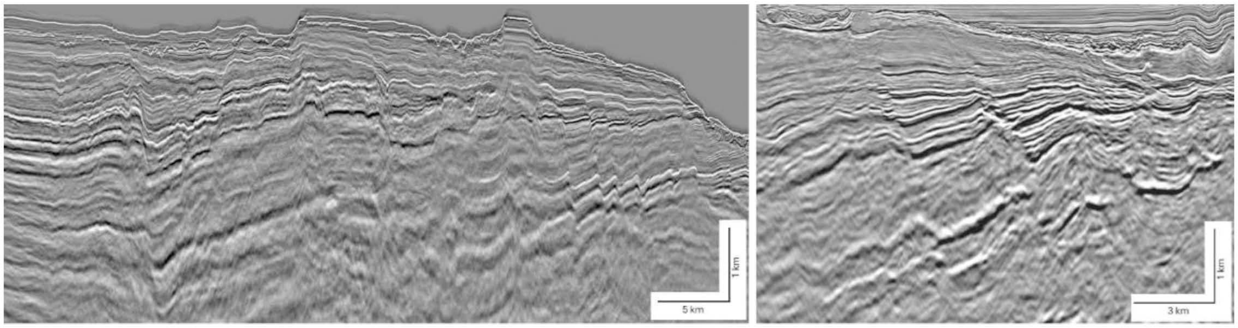

Figure 5—Two example seismic lines in the Nefertiti (left, Full stack KPSDM fast track volume) and the Depth Merge seismic volumes (right, Full stack KPSDM). The strong faulting related to the transform margin (right) is more severe towards the west, resulting in potential structural traps on the margin. Closer to shore, in shallower water there is still significant faulting on the platform area (left), producing structures in the Jurassic and Cretaceous strata that may provide viable traps for hydrocarbon accumulations.

Conclusions

This work highlights some of the key structural and stratigraphic elements observed using these new 3D seismic datasets. They can be put into a basinal geological context using the regional 3D depth merged volume. Within the Nefertiti survey there is sufficient faulting and high-quality imaging to suggest that structural closures will be able to be targeted for hydrocarbon exploration following accurate mapping in 3D, reducing exploration risk associated with trap definition. The presence of leveed channel and channel complexes in both the pre- and post-Messinian sections of the Merneith survey highlight the possibility for good quality reservoirs in the area, reducing the exploration risk for reservoir presence and quality. Scheduled exploration well results will be able to be linked to these new 3D seismic surveys using the Depth Merge volume.

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